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EXPERIMENTAL EVIDENCE FOR PARITY IMPURITY IN A NUCLEAR GAMMA TRANSITION*

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In this communication we present a preliminary account of an experimental investigation of parity admixture in nuclear states. Our measurements give evidence of a small parity admixture in a nuclear gamma transition of 482 keV in Ta^{181}. The size of the observed effect is in order-of-magnitude agreement with estimates based on the current-current hypothesis of weak interactions,[1] which predicts a strangeness-preserving nonleptonic weak coupling. Some of our results have been presented earlier.[2]

A number of experiments[3] have been done in the last few years with the aim of finding such a parity admixture. With the exception of recent work by Abov, Krupchitsky, and Oratovsky,[4] who have reported a parity-nonconserving term in the angular distribution of neutron-capture gamma rays, no evidence has been found up to now. Recently, Michel[3] has analyzed these experiments and calculated the magnitude of the effects of a parity-nonconserving force as postulated in the weak interaction scheme.

We report here on a measurement of the circular polarization of a gamma transition of 482 keV in Ta^{181}. This transition has been selected since it is found to be a particularly favorable candidate for finding a parity admixture. The transition taking place between a $\frac{5}{2}^+$ and a $\frac{7}{2}^+$ state with asymptotic numbers (402) and (404), respectively, according to the Nilsson scheme[5] has been observed to be strongly hindered. The $M1$ part is hindered by a factor of 3×10^6, and the $E2$ part which is the dominant (97 %) decay mode is hindered by a factor of 35 compared to the Weisskopf estimate. Following Michel's arguments and assuming a term of the type $\vec{\sigma}\cdot\vec{p}$ to cause an admixture of negative-parity states, one can estimate the size of the $E1$ matrix-element and thus the size of the $E1$-$M1$ interference. The Nilsson states $\frac{5}{2}^-$(503 and 303) and $\frac{7}{2}^-$(503 and 303) are presumably mainly responsible for this interference since transitions from and to these states are classified as unhindered. The $E1$-$M1$ interference gives rise to a circular polarization, P, of the gamma ray. This polarization can be expressed in the following way:

$$P=-[2/(1+q^2)]FR.$$

The quantity q is the mixing ratio between competing regular multipoles of lowest order ($M1$ and $E2$ in our case), F is the ratio of the parity-nonconserving potential of the form $H_{\rm int}=G''\vec{\sigma}\cdot\vec{p}$ to the total (parity-conserving) nuclear potential, and R is a quantity that depends on the nuclear structure only.

For the case of Ta^{181} the quantity F has been estimated by Michel[3] to be $F=8\times10^{-7}$. The quantity R is due to a contribution R^+ from the (503) particle states and R^- from the (303) hole states. For the former we have

$$R^+=\frac{\alpha(\frac{5}{2}^-503,\frac{5}{2}^+402)\mathfrak{M}(E1,\frac{5}{2}^-503\to\frac{7}{2}^+404)+\alpha(\frac{7}{2}^-503,\frac{7}{2}^+404)\mathfrak{M}(E1,\frac{5}{2}^+402\to\frac{7}{2}^-503)}{\mathfrak{M}(M1,\frac{5}{2}^+402\to\frac{7}{2}^+404)},$$

where α characterizes the amplitude of the admixture of the states from the $\vec{\sigma}\cdot\vec{p}$ force. We have, for example,

$$\alpha(\tfrac{5}{2}^-503,\tfrac{5}{2}^+402)=\frac{\hbar}{m_0r_0}\frac{\langle\frac{5}{2}^-503|\vec{\sigma}\cdot\vec{p}|\frac{5}{2}^+402\rangle}{E_{402}-E_{503}}.$$

A detailed calculation was recently performed by Wahlborn[6] for this case with the result

$$P=-1.3\pm0.4(e_1/e)\times10^{-4}.$$

e_1 is the effective charge associated with the electric dipole transition. The ratio e_1/e is of the order of unity. It is interesting to observe that this calculation not only gives the magnitude but also the sign of the polarization. This is due to the fact that the sign of the $M1$ matrix element of the 482-keV transition is known from the penetration term. An earlier estimate of $|R| \sim 2\times10^3$ has been given by Michel[3] using a different method, leading to a polarization of $|P| \sim 1\times10^{-4}$.

Below we describe the measurements of the degree of circular polarization. The experimental arrangement is depicted in Fig. 1. The 482-keV gamma ray of Ta^{181} emitted from the Hf^{181} source[7] passes through the core of an Armco iron electromagnet and is detected in a scintillation counter. Owing to the spin dependence of the Compton scattering, the transmission through the magnet depends on the direction of the magnetization as well as the polarization $\vec{P}$ of the gamma ray. The number of gamma quanta transmitted for the case that the momentum vector $\vec{P}_\gamma$ and the spin vector of the magnetic electrons $\vec{\sigma}_{el}$ are parallel (antiparallel) is denoted T^+ (T^-). The transmission rate is related[8] to the circular polarization of the gamma ray by

$$(T^+-T^-)/(T^++T^-) = -PNL\gamma\sigma_1 + \text{terms of increasing order in } P\,d\sigma_1/d\Omega,$$

where σ_1 is the spin-dependent Compton cross section, N the number of atoms per cm^3, L the length, and γ the number of magnetic electrons. In our geometry the contribution from singly and multiply scattered gamma rays is of the same size and sign as the contribution from the transmitted gamma rays.

The efficiency of the analyzer magnet shown in Fig. 1 with an effective core length $L = 3.6$ cm was calculated for our gamma-ray energy using a Monte Carlo method including up to four scatterings and was found to be 1.0×10^{-2}.

The detecting system consisted of a magnetically shielded lead-loaded plastic scintillation counter (5×10 cm), a 1-m-long Lucite light pipe, and a magnetically shielded 56AVP multiplier tube. The pulses successively passed through a tunnel diode discriminator, a 200-Mc/sec prescaler of 80, followed by two count-gates and two scalers of 10^7 capacity with print and punch readout. The counting rate was of the order of 6×10^6 counts per sec. The experiment was run with 20-second periodicity as follows: One of the count-gates was open for an 8-second counting interval. During the subsequent 2 seconds the gates were closed and the analyzer magnet polarity was reversed. Thereafter the other count-gate was opened, starting the second half of the cycle. The accumulated counts were recorded on tape after four cycles of either polarity. For each 24-hour run the data were analyzed with a computer and an error distribution was obtained. This error or frequency distribution had characteristically a width of 1.1 standard deviation if corrected for a small dead-time loss. In no case were there single points with more than 4.5 standard deviations from the average. The asymmetries in the transmission rates observed under various conditions are presented in Table I, column 2. Each set of runs for a given condition was sandwiched between runs of a control experiment designed to check on possible asymmetries of the system. In this control experiment (referred to as straight counting and listed in column 3), a Hf^{181} source was placed near the scintillation counter with a corresponding amount of lead in between to produce the same pulse-height spectrum, and hence the same discriminator curve. The gamma rays from this source were counted under exactly the same conditions. The instrumental asymmetry listed in column 3 was subtracted from the value in column 2. The difference, corrected for a 5-10% dead-time loss of the counting

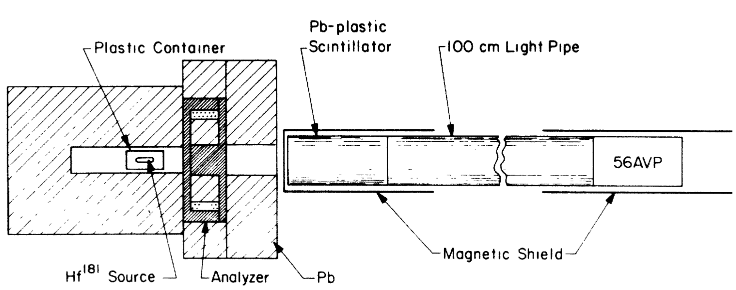

FIG. 1. Experimental arrangement for the detection of circular polarization.

Table I. Observed relative difference in transmission of the 482-keV gamma rays in Ta^{181} through magnetized iron. The values are corrected for radioactive decay.

Condition (1)	Run[a]	Observed asymmetry $(T^+-T^-)/(T^++T^-)$ in units 10^{-5} Transmission (2)	Straight counting (3)	(2)−(3) dead-time correction applied (4)
$Hf^{181}O_2$ sources	(*a*)	$+0.30\pm0.06$	$+0.07\pm0.07$	$+0.24\pm0.10$
	(*b*)	$+0.56\pm0.10$	$+0.42\pm0.09$	$+0.15\pm0.14$
	(*c*)	$+0.71\pm0.14$	$+0.39\pm0.16$	$+0.33\pm0.22$
	(*d*)	$+0.14\pm0.09$	-0.12 ± 0.11	$+0.28\pm0.16$
Average (*a*) to (*d*)				$+0.24\pm0.07$
$Hf^{181}O_2$ diluted diamond powder	(*e*)	0.00 ± 0.06	-0.15 ± 0.08	$+0.17\pm0.10$
	(*f*)	$+0.15\pm0.06$	0.00 ± 0.06	$+0.17\pm0.09$
	(*g*)	$+0.04\pm0.07$	-0.14 ± 0.07	$+0.20\pm0.10$
	(*h*)	-0.01 ± 0.09	-0.19 ± 0.10	$+0.18\pm0.13$
Average (*e*) to (*h*)				$+0.18\pm0.05$
Control experiment Co^{60}	(*i*)	-0.09 ± 0.06	-0.10 ± 0.07	$+0.02\pm0.09$

[a]Run (*a*): stray field not compensated. Run (*b*): same as (*a*), but magnetic shield modified. Run (*c*): magnet turned 180° compared to (*b*). Run (*d*): stray field compensated to $\Delta H \geq 10^{-5}$ G at site of multiplier. Runs (*a*), (*b*), (*c*), (*d*), (*e*), and (*g*), setup no. 1; Run (*f*), setup no. 2; Run (*h*), setup no. 3.

system, is given in column 4.

Among the possible causes for an asymmetry of the counting system are obviously the effects of the alternating stray magnetic fields on the scintillation counter and on the multiplier, as well as minute asymmetries in gating and in the counting channels. The stray-field effects were carefully studied. For Runs (*a*) to (*d*) of Table I the uncompensated stray fields were approximately $\Delta H \simeq 10^{-3}$ G. For all other runs a compensation coil was used reducing the stray field to $\Delta H \simeq 10^{-5}$ G.

In addition to the mentioned effects on the counting system, other effects could give rise to an apparent polarization. We mention (1) asymmetry in magnetization and magnetostriction of the analyzer magnet, (2) polarization of the source nuclei in the stray field of the magnet, (3) internal bremsstrahlung following beta decay of Hf^{181}, and (4) external bremsstrahlung. Estimates show that the effects (1)-(3) are too small to be of importance in our case. In particular, in our arrangement the internal bremsstrahlung can account for an apparent polarization of not more than $P \simeq -0.2\times10^{-4}$. The external bremsstrahlung if all beta particles were stopped in HfO_2 ($Z_{av} \simeq 60$) in our geometry can give rise to a value of P of not more than -0.6×10^{-4}. This estimate is subject to some uncertainty, however, and a check on possible effects due to the Z-dependent external bremsstrahlung was made. Several dilute sources were prepared [Runs (*e*) to (*h*), Table I] by mixing the enriched $Hf^{180}O_2$ target material with diamond powder in the ratio 1:2.5 by weight, reducing the effective Z and thus the bremsstrahlung yield by a factor of about 3. It can be seen by comparing the average value of Runs (*a*) to (*d*) and (*e*) to (*h*) that external bremsstrahlung cannot account for the entire observed asymmetry.

Finally, a further control experiment was performed using a source of Co^{60} [Run (*i*), Table I]. The unhindered $E2$ transitions in Ni^{60} are not expected to show a parity effect. Within the error limits no asymmetry was found.

From the average of the values in column 4, Table I, we find an asymmetry of $+(0.20\pm0.04)\times10^{-5}$, implying a gamma-ray polarization of

$$P = -(2.0\pm0.4)\times10^{-4}.$$

The indicated error is due to counting statistics of the data in colums 2 and 3 only and does not include the error on the Co^{60} control experiment, nor does it include any possible systematic error.

A value of $P = -(5 \pm 2) \times 10^{-4}$ has been reported previously[2] as a result of a similar experiment using a "slow" NaI counting system and a considerably thicker (8.5-cm) analyzer magnet. In obtaining P only the transmission term in the analyzer efficiency has been considered. If we also include scattering terms the deduced polarization P would be reduced by nearly a factor of 2. Due to the longer magnet-core length, the contribution from bremsstrahlung was entirely negligible in this experiment.

For some experiments we have also used a hollow cylindrical magnet arrangement such as described by Boehm and Wapstra,[9] in which only forward-scattered gamma rays are measured. Owing to its lower efficiency this system gave a somewhat smaller counting asymmetry leading to a polarization of similar magnitude and sign.

We conclude from the observation of a circular polarization that there is a parity-nonconserving admixture in the nuclear states of Ta^{181}. The observed sign and magnitude suggest that we are dealing with the nonleptonic weak coupling predicted by the current-current picture of weak interactions. Our results are in accord with the recent experimental findings by Abov, Krupchitsky, and Oratovsky.[4]

Further work is in progress with highly diluted sources of Hf^{181}. Other favorable gamma transitions, notably those in Tl^{203} and Lu^{175}, are also being investigated.

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